A Sketch of the Geological Structure of the Malay Peninsula.

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It is now some considerable time ago that I was first invited to contribute a paper to the Journal of the Straits Branch of the Royal Asiatic Society on the geology of the Malay Peninsula, but it was only when this invitation was repeated recently that I felt justified in attempting any such sketch, and that because after some years work I feel that the main points in the geology of the Peninsula are becoming clear and that it is possible to trace some of the steps in the history of this part of Asia before ever it existed as a Peninsula.

It is my purpose then in this paper to show how far the information gained during the economic work of the last seven years assists the science of geology in its great object, which is the unravelling of the history of the globe, with the help of the evidence afforded by the physical features of the earth's surface as it exists at the present day.

The chief physical features of the Peninsula with which we shall be concerned are the mountain ranges, and a strip of flat land with isolated hills that occurs on either coast, but is particularly well marked on the west from Kuala Langat northwards. To take the mountain ranges first, there are three distinct types, whose position and nature must be examined in some detail.

Beginning in the north, a remarkable but little known feature is found in Kedah. As one approaches the mouth of the Kedah River from Penang, there is seen on the left of the entrance a big mass of limestone rising out of the flat ground and to the right of it a more distant range of hills. Through

the Gap between the limestone mass and the hills is seen a stretch of low-lying country with no hills in the back-ground and over which an earth road has been made from Alor Star to Singapore on the east coast of the Peninsula. This distant range of hills rises to the east of the Singgora road from the beautiful flat padi-fields that surround Alor Star, about nine miles out from the capital, and its prolongation northward can be followed either by travelling along the road or by ascending the Kedah River, when it is seen to enter Siamese territory, and although I cannot say that I have proved the point by following the chain, which along the whole length that I have examined it, is composed of quartzite with clayslate and conglomerate, to its northern limit, there is very good reason to believe that it is continuous as far as Singgora, where sandstone, probably resulting from the weathering of quartzite, is known to form hills.

Here then we have a barrier of sedimentary rocks trending north and south, and cutting off all the hill ranges of the Peninsula from the Isthmus. I must add that it has been stated that the Lakawn range, which lies to the north-west of this barrier, enters the Peninsula to form the main granite range, and that this statement has found its way into a translation of Suess's great work "Der Antlitz Der Erde," but it is incorrect. No range of hills cuts through this north and south barrier of quartzite and clayslate. The main granite range rises to the east of it, in rugged country about which little is known.

This range of quartzite and clayslate is of great interest in connection with the present configuration of the Peninsula and also with its past history, but it is only one of several such ranges.

The most notable of these, both on account of its grandeur and because it contains the highest peak in the Peninsula, is the Tahan Range, part of which is in Pahang and part in Kelantan. This is composed of quartzite, clayslate and conglomerate, and is part of a broad outcrop of those rocks that is believed to traverse the whole of Pahang and to reappear in

Singapore. Another range of the same composition is the range of foothills in Pahang that lies to the east of the main granite range: while on the western side of the Peninsula the small Semanggol range between Larut and Krian is composed of the same rocks. Other hills in South Perak and Selangor are outcrops of similar rocks and may prove to be of the same age, and many small exposures of conglomerate, quartzite, and clayslate are known that can be regarded as contemporaneous with more certainty.

These mountain ranges have preserved for us a mass of rocks that were formed at the mouth of a big river, or perhaps of more than one river, and the fossils found in them, unfortunately few in number, prove that they are an extension of the great Gondwana Series of India, marking a portion of the coast of what is known as Gondwana-land, a continent that existed in the Palaeozoic Epoch and gradually broke up during the Mesozoic. The extent of this continent is a difficult question that brings palaeontological evidence into conflict with the theory of the permanence of Ocean basins. The former points to a land connection between India, Australia, and South Africa, that is to say to a large tract of land occupying the present position of part, at any rate, of the Indian Ocean. On the other hand we have the view held by many eminent scientists, that the great ocean basins as we know them now were formed when first land and water were differentiated on the surface of the globe. It is a question that cannot be discussed at length here, and we must be content in saying that Gondwana-land was a reality but that its form and extent are uncertain.

The Gondwana rocks of the Peninsula were laid down in the sea on the north or north-east coast of Gondwana-land. We now have a starting point from which to extend our knowledge if possible: that at one time of the earth's history, namely during the deposition of part of the Gondwana Series of India, which dates from the early Permian, this portion of the globe was a shallow sea off the coast of Gondwana-land. What was it before then?

We find an answer to this in the second type of mountain ranges, the limestone hills. These are part of a wide-spread formation of limestone and calcareous clay-slates that are known to be of Carboniferous or perhaps Permo-Carboniferous age, as far as the exposures in Pahang are concerned, and which are probably of the same age elsewhere in the Peninsula. The nature of these rocks, the abundant remains of shells, corals and crinoids in the limestone where it is not crystalline, and the fine grain of the calcareous clay slates, point to their having been deposited farther from the shore than the Gondwana rocks and in a deeper, clearer sea. We also know from volcanic rocks associated with these calcareous rocks, that the sea floor during this period was from time to time torn open by eruptions and covered with layers of ash and lava.

This takes us one step farther back, and could we accept the statements that have been made by some writers about Archaean rocks occurring in the Peninsula, we should be able perhaps to glean a wealth of information about land and sea prior to the Carboniferous period, but unfortunately our knowledge, but recently acquired, of the pre-Carboniferous land and sea is small, although of extraordinary interest. Before discussing this, however, there are other points that claim attention.

Two types of mountain ranges give us information about the earlier history of what is now the Peninsula, the third type, the big granite ranges, carries us on to later times. The granite of all the Peninsula ranges is, as far as we know, younger than the Gondwana rocks and the calcareous rocks, it is but again, as far as we know, the youngest rock in the Peninsula with the exception of a few later igneous dykes intrusive into it; and the recent surface deposits. In geological chronology we cannot fix its date exactly, but without giving the evidence in detail it may be said to be probably cretaceous. As the granite is the latest, with the above reservation, of the rocks to enter into the composition of the Peninsula, it would be safe to assume that the events which led to its intrusion

were largely instrumental in determining the present configuration of the country. This was the case, and in order to see how it came about, let us try to imagine what took place in the earth's crust when the granite took up its present position in relation to the older rocks.

After the Gondwana rocks that are preserved in the hill ranges had been deposited, sedimentation continued until the calcareous Carboniferous rocks and the Gondwana rocks had above them a huge pile of younger rocks. At the same time lateral pressure was brought to bear on them, now deep down in the earth's crust and at a high temperature, with the result that they were to a large extent crushed into small folds and bent as a whole into a series of low arches or anticlines, the axes of which trended approximately north-north-west, south-south-east, and were much longer than their span.

Below the calcareous rocks, and probably separated by a considerable thickness of still older rocks was a vast molten or viscous mass, laden with steam and other vapours, struggling to rise from the depths. This was the granite magma, and the bending of the Gondwana and other rocks, the close folding with the consequent loss of stability as a lid to the granite magma, enabled the latter to be forced upwards, partly by pressure from other portions of the earth's crust, and partly by the entangled steam. The granite magma rose underneath a series of arches of which the points least able to resist the attack of the rising mass were the apices. The tremendous force pressed the molten mass against the under side of these arches, the rocks that formerly were between the calcareous rocks and the granite magma, had been broken up, sunk, and perhaps completely dissolved in the latter; the resistance to the rising mass became less and less as pieces of the arch, partially dissolved along planes of folds and faults, dropped into the magma; and finally the tops of the arches gave way completely, they were broken up into blocks that slipped one against another while huge masses dropped bodily into the magma, allowing the granite to rush upwards and fill the

spaces in the now shattered arches with hot, viscous rock. Finally, when the full forces that urged the granite upwards were nearly spent, the whole mass round about the remains of the Gondwana and calcareous rocks cooled and began to solidify, and after spurts of vapour and molten rock, carrying tin amongst other things, had marked the last expiring efforts of the magma the granite became a rigid mass.

But now, after the Gondwana and calcareous rocks had been buried for so long deep in the earth's crust, the rocks that formed the surface were being fast worn away by denudation, until in the course of time the remains of the arches and the solid granite were close to the surface. Before denudation brings them to the light, let us examine their arrangement in more detail.

Dislocation on a large scale had destroyed the former continuity of the rocks composing the arches, and large blocks had dropped down into the magma, their place being taken by granite. The arches had in all probability been forced upwards to some extent when the pressure from the magma was first felt, but when their stability had been completely destroyed the dislocations were caused by downward movements. They were what are known as "faults," and they so affected the beds with which we are immediately concerned that Gondwana rocks dropped down so as to be side by side with the calcareous rocks. The main dislocations occurred along lines trending roughly N.N.W.-S.S.E., but there is evidence of other dislocations at right angles to these lines. In the portions of the arches near those that the granite had broken through, that is near the weakest places, the close folding of the rocks under pressure had caused the bedding of both series to appear vertical although had it been possible to bore through the vertical Gondwana beds in any one block we should have come to vertical beds of calcareous rocks below. In both series there were rocks of varying hardness. The conglomerates and quartzites of the Gondwana rocks were harder than the clay slates of the same series, the calcareous clay slates were not so hard as the limestone that had been

rendered crystalline by the tremendous lateral pressure in the earth's crust, so that could a horizontal section have been cut through the remains of the arches and could any one have walked over it from the W. S. W. towards the E. N. E. he would have passed over bands of hard quartzite, hard conglomerate, hard limestone, hard granite, and comparatively soft bands of clay slates, not in the order given, but in a sequence determined by the original bedding of the Gondwana rocks and the calcareous series, the dislocations, and the position of the zones of irruption of the granite.

At what period the denudation of rivers and sea first touched the materials of the shattered arches we do not yet know. We can be sure, however, that whenever the wearing away of these rocks commenced, it canno have been long before the superior hardness of the granite, quartzite, conglomerate and limestone, shewed itself by greater resistance to rivers and sea, resulting in the formation of ranges of hills inland and islands on the coast, such as Pulau Tiuman on the east coast, Pulau Pinang, and the Pulau Sembilan on the west.

The denudation of the rivers acting on the remains of the great arches of the Gondwana and calcareous rocks and the granite has carved out our mountain ranges: but what proof have we now on the surface that the dislocations in the arches ever took place? In Kinta, fortunately, we have good evidence of them. I cannot do more here than describe the evidence briefly. On the east of Gunong Tempurong, a limestone hill south of Gopeng, traces of schists, representing altered Gondwana rocks, on the edge of the granite of the main range and at the base of a perpendicular cliff of limestone, shew the position of one of the greater dislocations that resulted in a mass of the arch falling into the magma and allowing the granite to take its place. We cannot say this is a fault with so many feet "throw," because the thrown side has disappeared entirely except for the traces of schists.

The cliff that I speak of is about 800 feet high and the distance across the main granite range to the calcareous rocks in Pahang is about thirty miles. It is difficult to imagine a

strip of the earth's crust of that width, the length of the main range, and 800 feet high, sinking into a cauldron of molten granite, but we can only take that 800 ft. to be the minimum height of the mass that has been utterly engulfed, as shewn by the remnants of schists torn off againt the limestone wall and fixed in their present position by the granite magma surging upwards.

Again, although in Pahang there is evidence of the limestone hills having been formed by resistance to denudation in unfaulted areas, in Kinta there is running up the east side of the valley a long fault parallel to the main granite range that has caused the formation of the bluffs on the west side of the limestone outcrops. A large mass of the limestone now forming the floor of the Kinta Valley was dislocated, with the result that soft beds of the over-lying Gondwana rocks were left against the hard unfaulted limestone, and when the Kinta river came into being it flowed over and wore away the soft rocks, leaving the unfaulted limestone as cliffs, which are in geological terminology "fault-faces."

Of the transverse dislocation at right angles to the main faults there is good evidence at Gopeng. Here the continuity of the limestone foothills to the north is suddenly interrupted by a mass of Gondwana rocks, but the limestone hills reappear to the south again, and it is known that under the Gondwana rocks limestone occurs. It is clear that a block of limestone and Gondwana rocks, seven miles in width from north to south, has been let down between two transverse faults.

I mentioned above denudation by the sea as forming islands, and must now briefly explain how it has further affected the Peninsula. If any one visits the limestone hill described as being on the left hand side of the mouth of the Kedah river he will find strewn round the base of the cliffs abundant remains of recent corals and sea-shells. If he will proceed towards Singgora on the low rolling country to the west of the barrier range of Gondwana rocks, noting that the Kedah river emerges from these hills and does not flow over the low ground until it reaches the padi-fields of Alor Star, he

will perhaps ask himself why that low-lying country, drained by no considerable river, exists. The corals and shells at the base of the limestone hill in Kedah (Elephant's Hill) certainly mark an old sea-beach : the hill was once an island and the Alor Star padi-fields were covered by a shallow sea, and if it is once admitted that the country round Alor Star was recently sea, then a comparison of levels make it necessary to admit that a large portion of the Peninsula was recently sea also, and that the hills which rise from the mangrove swamps, such as the Dindings hills, Kuala Selangor hill, and Parcellar, were islands. With regard to the low-lying country west of the barrier range in Kedah, I have not seen any conclusive evidence myself that it also was covered by the sea, but Mr. H. N. Ridley tells me that the flora of the Peninsula north of Penang shows that the "flat area between Perlis and Gunong Jerai was for a long time under sea," so that it is not an unreasonable conclusion to come to that in recent geological times the Peninsula itself was an island.

We have now done what we can to trace the main points of the history of this part of the globe from the deposition of the calcareous Carboniferous rocks to the present time, and I must now describe the little that is known of its pre-Carboniferous history. This has been learned from part of the series of volcanic rocks found with the calcareous rocks on the one hand, and from part of the Gondwana rocks on the other.

In Pahang these volcanic rocks form an extensive series interbedded with the Carboniferous calcareous rocks, which proves, as before stated, that the sea-floor in those early times was periodically the scene of violent eruptions. The series consists of lavas and ashes, and there is evidence that the eruptions had not completely ceased when the deposition of the Gondwana began. These volcanic rocks, I have found, are not confined to Pahang and it will be of interest perhaps to many to know that the small island, Pulau Nanas, between Pulau Ubin and the Johore coast, where a large quantity of stone is worked for use in Singapore, is composed of these rocks. Pulau Nanas consists of lava and ashes that have been

altered and hardened by the adjacent granite of Pulau Ubin, which we will refer to as the Mesozoic granite, as being part of the granite whose history we have just traced. The lavas and ashes of Pulau Nanas then are certainly older than the Mesozoic granite, but if we examine the ashes on the north coast of the island closely we shall find that it contains angular fragments of granite that have been altered in the same manner as the ashes and lavas. Now we know that granite is not a volcanic rock: no volcano has ever been known to pour out granite as lava, and no volcanic ash resulting from the explosive force of steam on viscous granite has ever been found. But it is not uncommon to find in volcanic ashes portions of the wall of the vent by which the lava forced its way to the surface or the sea-bottom, and the simplest explanation, if not the only one, of the presence of those granite fragments in the Pulau Nanas ash, is that the vent passed through granite forming part of the sea-bottom, or perhaps in this case, of the land surface. Therefore before the Carboniferous volcanic rocks were poured out, an older granite mass had solidified. We will refer to this as the Palaeozoic granite.

Before leaving the neighbourhood of Singapore there is some more information to be noted in connection with this Palaeozoic granite. Gondwana rocks are largely exposed here and in a conglomerate bed I found two small pebbles of a rock composed of quartz and tourmaline. There are no rocks known in the older calcareous series from which such pebbles could have been derived, unless they be ashes such as those at Pulau Nanas containing fragments torn from a volcanic vent, but even in that case we should be obliged to regard those pebbles as derived ultimately from a mass that existed before the calcareous rocks were formed. As our knowledge of the Mesozoic granite leads us to expect quartz-tourmaline rocks to be connected with granitic rocks, we therefore suspect a possible connection between those pebbles and the fragments of Palaeozoic granite in the Pulau Nanas ash.

This suspicion is confirmed by what is undoubtedly the most interesting point that has come to light in the geology of the Peninsula, and one that is of far reaching significance in connection with the mining industry. When giving evidence of the dislocations in the arches of Gondwana and calcareous rocks, I cited as an example of transverse faults a block of land at Gopeng interrupting the continuity of the limestone hills. In this faulted area the limestone floor is covered by beds of stiff clay and beds of clay containing boulders. If we examine these clays where they about on the Mesozoic granite we see that they are certainly older than that rock. If we collect specimens of the boulders we find that boulders of tourmaline-schists, quartz-tourmaline rocks, quartz-tourmaline-mica rocks, are common, while occasionally a boulder of granite occurs, and as the clays are older than the Mesozoic granite, so must all these boulders be older also. The abundance of tourmaline rocks suggests the possibility of finding tin-ore and the mode of occurrence of much of the ore that is older than the Mesozoic granite, which has in places brought a second store of tin to further enrich them. Here is further evidence connected with the Palaeozoic granite that is almost sensational. This ancient granite that we know only from a few fragments and boulders gave birth to a tin-field before ever the Carboniferous calcareous rocks were deposited.

There is another peculiarity of these clays that would arrest the attention of any geologist, and that is the strong resemblance they bear to clays associated with glaciers, such as the "till" and boulder clays of England. Is anything known to geologists of glacial beds older than our Mesozoic granite? The answer is more satisfactory than some would expect, for in India, Australia, and South Africa there are preserved glacial deposits not only older than our Mesozoic granite, but at the base of Gondwana Series in India and its equivalents in Australia and South Africa. Owing to the strong tropical weathering, the evidence of glacial action in the Gopeng boulder clays is not as good as could be wished, but their position immediately above the limestone and the

nature of the deposits themselves leaves little doubt in my mind that they are approximately on the same geological horizon as the Talchir Boulder Bed of India, and like it, were connected with glaciers.

In conclusion I will summarize what we can say we know of the geological history of the Malay Peninsula. It has been impossible to give in the space of this paper all the evidence as it should be given, and I fear that in consequence some statements may appear to require further investigation, but I trust that it will be recognised that even in a jungle-covered, tropical country information can be gathered that is of value to those who care to enquire into the origin of such familiar objects as the hills and valleys of the country we live in.

1. In Carboniferous times the site of the Malay Peninsula was deep sea, lying off the coast of the now vanished Gondwana-land. On the bed of this sea corals and shells abounded, but periodical and violent eruptions of lava and ash must have been very destructive to life.

2. The sea-floor rose and about the opening of the Permian period the coast of Gondwana-land had so far advanced as to pour a huge accumulation of shallow water sediments on to the deep-sea Carboniferous deposits, and glaciers descended from the hills of this Gondwana-land coast, which were of tin-bearing granite depositing beds of clay and boulder-clay that are now being worked for their tin-ore.

3. The sea floor sank again and a pile of sediments was deposited above the Gondwana shallow water beds, with the result that they and the Carboniferous beds came to occupy a position deep in the earth's crust where they were subjected to great lateral pressure, resulting in close folding and the formation of a series of arches, and they also were affected by a large rise in temperature caused by their position in the earth's crust and by the heat developed during the folding.

4. The folding and consequent lessening of stability allowed a vast rock-magma to rise from the depths which ultimately shattered and burst through the arches and solidified as our well-known Mesozoic tin-bearing granite.

5. Meanwhile, or perhaps subsequently, denudation was attacking the deposits piled up above the Gondwana rocks, and in the course of time, the remains of the arches and the granite cementing these remains together were laid bare and carved out to form the surface of the Peninsula as we know it, to-day.

6. In recent times the Peninsula was an island and the flat mangrove swamps on its coasts were sea.